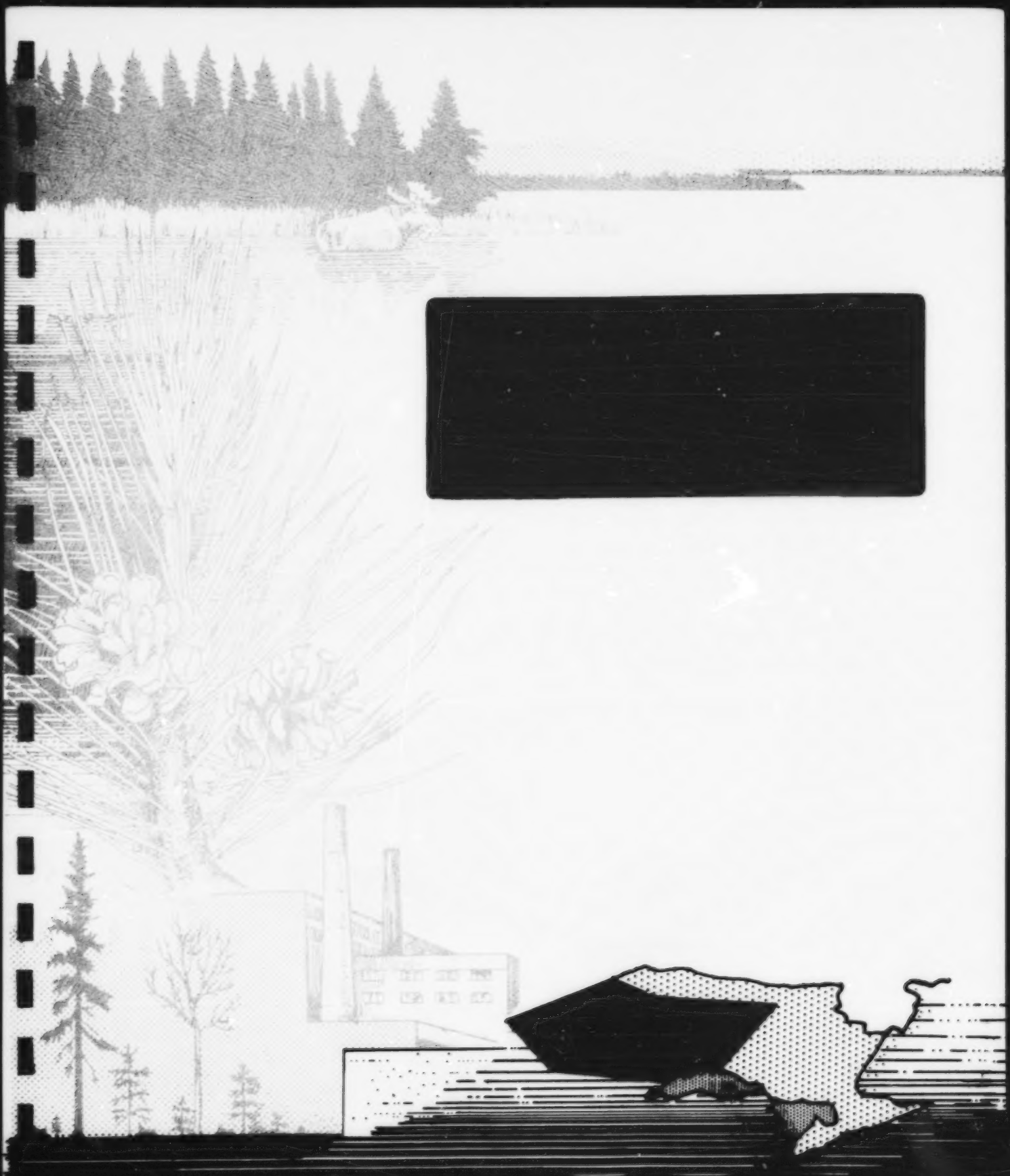

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EVALUATION OF STAND VULNERABILITY TO SPRUCE BUDWORM ATTACK USING GIS

by

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SUMMARY

This paper describes a project in which a GIS approach was used to study a 100 km2 forest area in northwestern Ontario supporting extensive mixedwood stands with a high proportional cover of balsam fir that has been heavily attacked by spruce budworm during the last 10 years. A modelling approach, using factors such as present forest composition, stand age, soil moisture regime, soil texture and interpreted balsam fir components in the overstory, was applied to help determine future site and stand vulnerability to budworm attacks. Some implications and advantages of this approach to estimating stand vulnerability to spruce budworm are discussed. The study was supported by a variety of information databases including NWO FEC Vegetation and Soil Types (V-types and S-types). Photo interpretation and mapping techniques developed during the study for the V- and S-types are also described in the paper.

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1.0 INTRODUCTION

Spruce budworm (Choristoneura fumiferana Clem.) feeds heavily on foliage of balsam fir and white spruce (and to a lesser extent, red and black spruce) throughout the boreal forest of Canada. It is Canada's most destructive forest pest (Anon. 1988a). In Ontario, where a number of significant outbreaks have occurred over the last 5 years, budworm is responsible for an average annual depletion of 11.6 million m^3 of wood, an amount that represents over one-half of Ontario's total annual harvest (Anon. 1988b).

In spite of this pest's considerable impact, control and ameliorative measures are still not well established. In 1987, for example, some 7.19 million ha were moderately to severely defoliated in the province by budworm, but only 76,520 ha or just over 1% of this was aerial treated, using the bacterial insecticide Bacillus thurigiensis (Anon. 1988a). A number of options for control are expensive, impractical, untested or environmentally unsuitable.

In general throughout Canada, silviculturally-based "preventative approaches" which aim to reduce wood losses brought about by spruce budworm are still poorly focused. A forest ecosystem's vulnerability to spruce budworm corresponds to the sum of characteristics which predispose it to damage or mortality during an attack of a given severity (MacLean 1980). Stand vulnerability to spruce budworm is affected by mensurational, ecological and entomological characteristics (Blais 1958, Frank and Bjorkbom 1973, Hix et al. 1987, Mott 1963). Gagnon and Chabot (1989) summarize the current state of knowledge on host / spruce budworm / environment relationships, presenting one method of classifying balsam fir-dominated stands using a "vulnerability index".

Particularly in scenarios where the entire allowable cut is needed to furnish mills, it is imperative that losses caused by budworm be minimized. To do this, industries need to be able to identify and weigh together those factors that influence the natural vulnerability of forest ecosystems to diverse, naturally occurring destructive agents. Furthermore, forest industries need workable techniques for integrating such information into management planning and operational practice.

In recent years two important developments have occurred that will enable the forest management planner to more effectively address complex issues such as stand vulnerability to spruce budworm attack. On one hand, to address these complex issues more comprehensive stand and site information is required. In Ontario, an ecologically based system of forest site classification system (NWO FEC) has been developed and provides a technique for generating this comprehensive data base (Sims et al., 1989). At the same time, PC and micro based Geographic Information Systems (GIS) technology has emerged as a means for integrating and modelling these multiple factor data sets for a wide range of forest planning and management programs.

The classification system, which consists of 38 Vegetation Types (V-types) and 22 deep and shallow Soil Types (S-types), is seen to be an integral part of future forest management and planning activities in northern Ontario as it will provide much of the additional site information required for more sophisticated forest management programs. For example, a number of the factors affecting stand vulnerability to budworm attack (e.g. stand composition, age, density, and soil texture, drainage and depth) which are not all available from (or normally collected as part of the existing forest inventory program) existing forest land classification maps (e.g. the FRI), will

be collected as part of the NWO FEC classification. Finally, although the NWO FEC classification system has been applied at the field level, photo interpretation and mapping aspects of the classification have not yet been formally addressed.

A number of PC and mini-based GIS systems are currently being introduced in Ontario (e.g. TYDAC SPANS and ESRI ARC/INFO) and studies are being undertaken to test and develop techniques for using these systems in the forest management planning process.

In anticipation of the integration of the NWO FEC classification system into forest management planning activities, the need to develop photo interpretation and mapping techniques for the classification system and the increased use of GIS technology in forest management, a study designed to examine the use of GIS and stand related NWO FEC information for assessing spruce budworm vulnerability was carried out. Photo interpretation keys for mapping the NWO FEC V- and S-types were developed, and three approaches for assessing stand vulnerability to spruce budworm were applied and compared in the study area using GIS modelling. Results are briefly considered in terms of implications and advantages of this approach for estimating stand vulnerability to spruce budworm.

2.0 STUDY AREA

The 10 X 10 sq km Sapawe study area (center: 91 10' W, 48 58' N) is located on the National Topographic Series 1:50,000 scale mapsheet "SAPAWE 52B/14". The study area, selected to be representative of forest cover and soils conditions in the general Atikokan - Ignace - Dryden forest area, lies within the Boreal Forest Region (B.11, Upper English River; Rowe 1972), 80 km northeast of Atikokan, Ontario. There are a considerable variety of forest cover types, but balsam fir and black spruce mixedwoods predominate. Other common overstory components are jack pine, white birch, trembling aspen, white spruce and red maple.

The general terrain is rolling to rugged. Soils of the study area are predominantly loamy or sandy, and are glacially worked; ground moraines are most common but there are some well-defined outwash, alluvial and lacustrine deposits as well (Zoltai 1965, Sado and Carswell 1987). There are remnant patches of organic soil throughout the area supporting black spruce. There is some shallow soil with outcropping Precambrian bedrock.

Portions of the study area have been actively logged; about 1/5 of the land area has been clearcut, mostly with progressive patch and block cuts, over the last two decades. There is a well-developed network of logging roads throughout much of the area. There has been considerable budworm damage over the past 10 years with mortality greatest following severe outbreaks in 1981-1983 and 1986-1987. In recent years this has resulted in considerable blowdown, especially along the exposed edges of dead and dying stands.

3.0 STUDY APPROACH

3.1 Field Reconnaissance

The study area was initially stratified for sampling using a combination of general surficial landform (Anon. 1985, Sado and Carswell 1987) and Forest Resource Inventory (FRI) map polygons. This information was transcribed onto a 1:15,840 chronoflex base map to serve as a first order stratification for ground truthing studies.

Field work was conducted during May to July, 1987. Polygons were selected for sampling and were visited in the field by 3-person field crews. Crews located polygons on the ground using field copies of 1:15,840 and supplementary 1:8,000 black and white aerial photos. Photos had polygons for sampling transcribed onto them, with transect lines, number of sample points (usually 10-12 per polygon) and bearings (in compass degrees) laid out. Access for the transect work was by vehicle or motorized canoe (using lake and river access), augmented as required with some limited use of helicopters, floatplanes and all-terrain vehicles.

All ground distances were chained and tied in to line starts and ends on the photos. At all sample points, crews collected information on ecosystem classification, soil texture and moisture regime, landform type, percent bedrock and/or surface stoniness, percent slope, and forest and FRI cover type. Prism sweeps were made for stocking and basal area. Soil sampling was accomplished with an auger. Photos were field-annotated with additional forest cover and other information.

3.2 Photo Interpretation, Mapping and GIS Database Development

Using the 1:15,840 FRI maps as the mapping framework, additional vegetation, soil and landform information was derived through photo interpretation of the NWO FEC S- and V-types. Information acquired during field studies was used to calibrate photo interpretation results. Photo interpretation "keys" were developed and applied for forest ecosystem and soil feature mapping. The keys, similar in concept to those developed for field application of the FEC V- and S-types, provided a method for consistently interpreting the FEC types on aerial photographs. Consistency was particularly important since more than one interpreter was involved in the mapping program.

Several information sources were consulted during the delineation of photo and map units, including digital LANDSAT MSS and TM imagery at several recent dates; 1:15,840 b&w stereo air photos obtained in summer, 1982; supplementary 1:8,000 b&w stereo air photos (9X9" format prints) acquired during June, 1987; and, 1:4,000 colour stereo photo-strips (35 mm) flown during fall, 1988. Most photo interpretation was conducted using the 1:8,000 stereo photographs. Using a JENA Sketchmaster, results were transferred to 1:15,840 base maps. Several maps were prepared, including soil features, FRI units, vegetational cover and Northwestern Ontario Forest Ecosystem Classification (NWO FEC) units (Sims et al. 1989).

During winter/spring, 1989, map layers were digitized, cleaned and verified, and subsequently imported into a TYDAC Inc. SPANS GIS at Forestry Canada, Ontario Region. Computerized attribute files, including point sample data collected during field transect surveys, as well as photo-interpreted polygon information, were imported and linked for analyses to their appropriate map files.

3.3 GIS Model Development

Analytical models were constructed using various data handling and modelling routines available in TYDAC SPANS GIS software. During the modelling process, a distinction was made between "susceptibility" which is related to the probability of a stand being infested irrespective of the damage that may potentially occur, and "vulnerability" which refers directly to the given probability a stand has of being damaged or killed once an infestation has occurred.

4.0 RESULTS AND DISCUSSION

4.1 Photo Interpretation Keys

V- and S-type keys have been developed for the study area, and are presented in Figures 1 and 2. The keys have potential for wider geographic application. The V-type key in particular has been tested in a number of areas throughout northwestern and north central Ontario and found to be reasonably robust. The soil key however is less robust and requires validation/modification prior to use in other areas.

At a photo scale of 1:15,840 the 10m x 10m FEC field plot represents an area 0.6mm x 0.6mm. Such an area is simply too small at this scale to reliably interpret FEC V- and S-types. It was decided to adopt a minimum interpretation area or unit (MIU) of one hectare for mapping purposes. The MIU at a scale of 1:15,840 is 0.63 cm^2 and can be effectively used for interpretation purposes. An MIU acetate overlay template was prepared for use during the interpretation phase of the project (Figure 3). The template is useful during the early stages of interpretation as a guide.

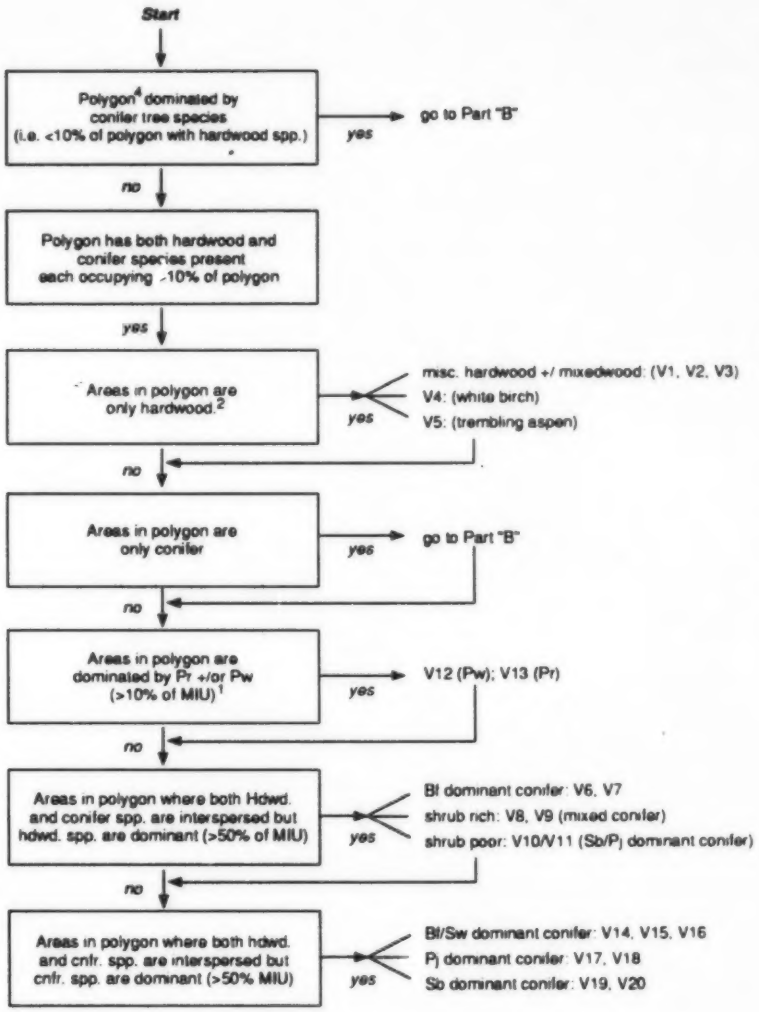
4.1.1 Photo Interpretation Key to the NWO FEC V-types

The photo interpretation key to the V-types is similar to the NWO FEC field keys in that it is divided into a Part "A" and Part "B" (Figure 1). Part A includes V-types 1 - 20 (hardwoods, hardwood dominated mixedwoods and conifer dominated mixedwoods), Part B includes V-types 21 - 38 (conifer only types). The interpreter proceeds through the keys following a simple "yes" or "no" format. It is useful to have at hand the NWO FEC Vegetation Key (Parts A and B) since a number of the V-types are differentiated on the basis of specific shrub/herb/moss conditions. Information gathered during the field reconnaissance stage of the project is important at this point. For example, V-types 19 and 20 are both black spruce dominated mixedwoods however, V-19 is a herb/shrub-rich condition whereas V-20 is a feathermoss-rich (herb/shrub poor) condition. Field survey information is essential in describing the general trends associated with a particular area and in differentiating such types. Similar field information is required for differentiating such V-types as V-6/V-7, V-17/V-18, V-9/V-10, V-36/V-37.

4.1.2 Photo Interpretation Keys to the NWO FEC S-types

The photo interpretation key used for the Sapawe S-types is (Figure 2) used in a fashion similar to that described for the V-type key. The interpreter proceeds through the key following a simple "yes" or "no" format until the dominant S-type(s) for the

Photo interpretation key to the NWO-FEC V-Types *Part "A"*



Notes:

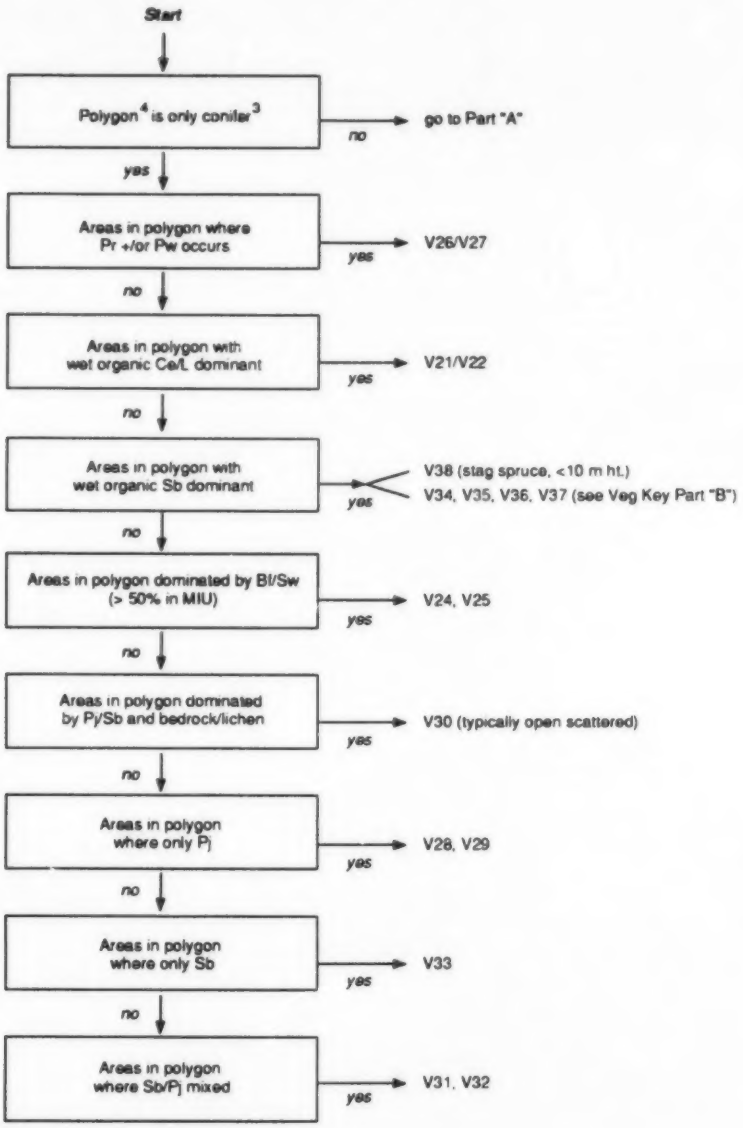
1 *Minimum Interpretation Unit (MIU) is 1 ha. at a scale of 1:15,840, the MIU is 0.6 cm².*

2 *"Only hardwood": MIU has <10% conifer component.*

3 *"Only conifer": MIU has < 10% hardwood component.*

4 *Minimum area cover for V-Type to included in polygon description is 10% total cover.*

Photo interpretation key to the NWO-FEC V-Types *Part "B"*



Notes:

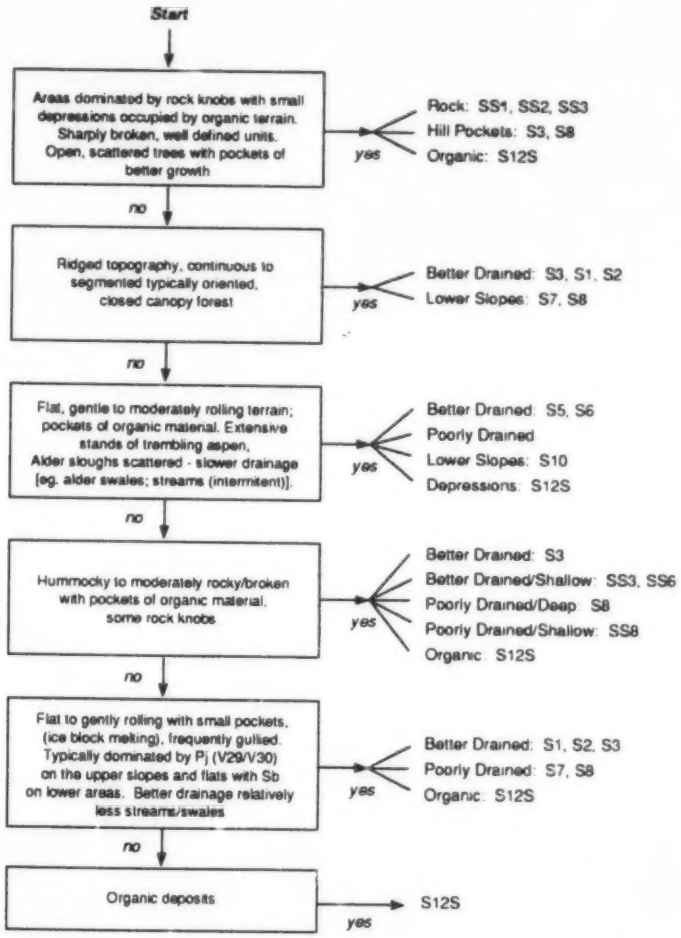
1 *Minimum Interpretation Unit (MIU) is 1 ha. at a scale of 1:15,840, the MIU is 0.6 cm².*

2 *"Only hardwood": MIU has <10% conifer component.*

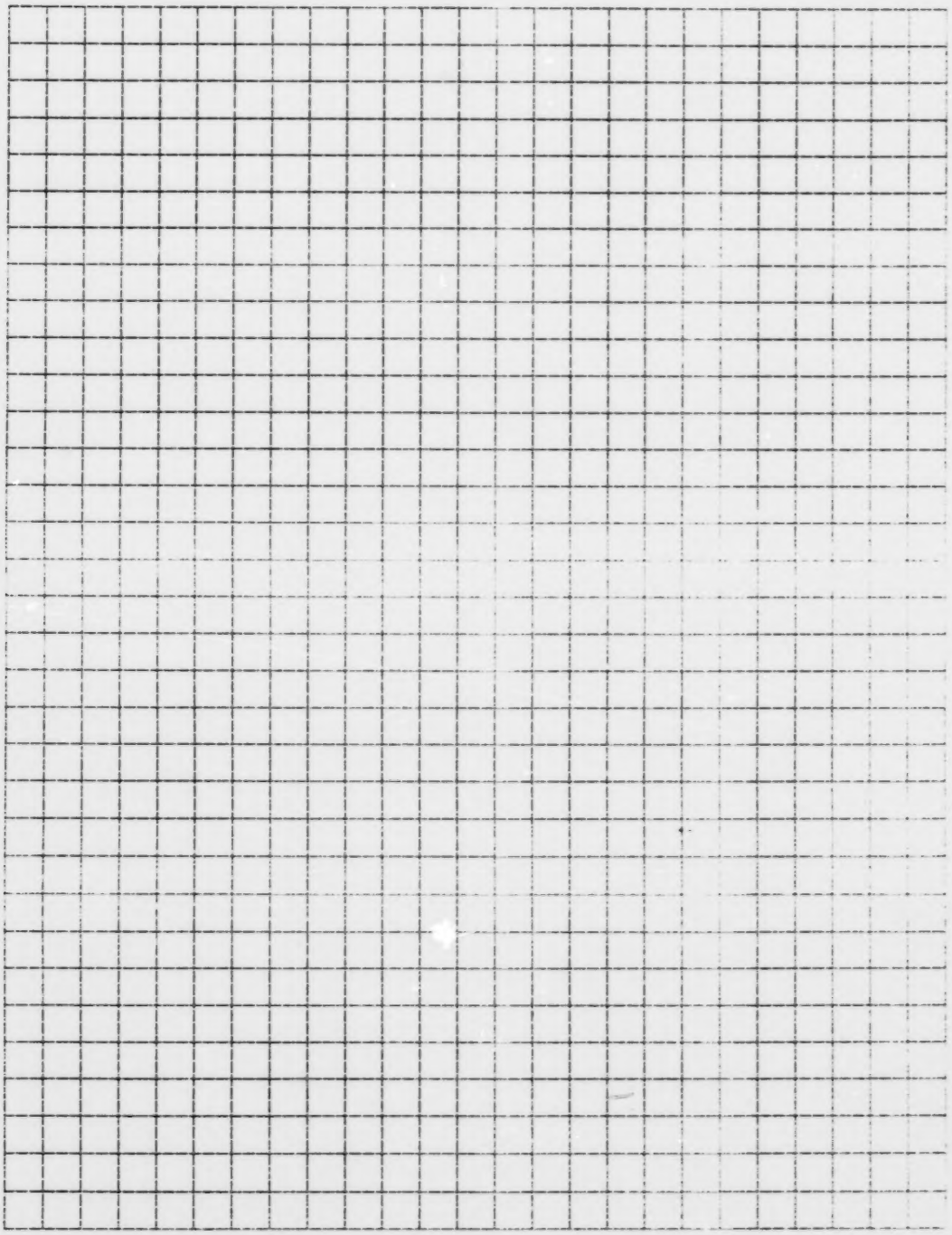
3 *"Only conifer": MIU has < 10% hardwood component.*

4 *Minimum area cover for V-Type to included in polygon description is 10% total cover.*

NWO-FEC S-Type photo interpretation key
Sapawe Forest Management Unit


Start
Areas dominated by rock knobs with small depressions occupied by organic terrain. Sharply broken, well defined units. Open, scattered trees with pockets of better growth
yes
Rock: SS1, SS2, SS3
Hill Pockets: S3, S8
Organic: S12S
no
Ridged topography, continuous to segmented typically oriented, closed canopy forest
yes
Better Drained: S3, S1, S2
Lower Slopes: S7, S8
no
Flat, gentle to moderately rolling terrain; pockets of organic material. Extensive stands of trembling aspen, Alder sloughs scattered - slower drainage [eg. alder swales; streams (intermitent)].
yes
Better Drained: S5, S6
Poorly Drained
Lower Slopes: S10
Depressions: S12S
no
Hummocky to moderately rocky/broken with pockets of organic material, some rock knobs
yes
Better Drained: S3
Better Drained/Shallow: SS3, SS6
Poorly Drained/Deep: S8
Poorly Drained/Shallow: SS8
Organic: S12S
no
Flat to gently rolling with small pockets, (ice block melting), frequently gullied. Typically dominated by Pj (V29/V30) on the upper slopes and flats with Sb on lower areas. Better drainage relatively less streams/swales
yes
Better Drained: S1, S2, S3
Poorly Drained: S7, S8
Organic: S12S
no
Organic deposits
yes
S12S

NWO-FEC photo interpretation key



Minimum Interpretation Unit (MIU)

Developed for use with 1:15,840 scale b&w aerial photographs.
Each square (MIU) represent 1 ha. at a scale of 1:15,840

polygon are described. In this study, both shallow and deep soil types are combined into a single key. For larger and more complex areas, two separate keys similar to that developed for the V-types may be required.

4.2 GIS Budworm Susceptibility Modelling

Following development of the GIS database, a number of budworm susceptibility models were developed as part of the modelling process. Initially, a budworm susceptibility map for the Sapawe area was prepared, based simply upon a minimum "40% dominance" criteria by balsam fir plus white spruce in the overstory. Polygon labels associated with the FRI map were used so that those labels with greater than 40% balsam fir plus white spruce [i.e., representing basal area estimates as interpreted from 1:15,840 stereo aerial photos] were defined as higher priority areas for harvest. Although not a common and widespread field practice, this approach is currently employed by field foresters working in the Ontario Ministry of Natural Resource's North Central Administrative Region, which includes the Atikokan - Ignace - Dryden area (Anon. 1988c). Balsam fir plus white spruce overstories with greater than 40% dominance were considered to be "susceptible" to infestation (i.e., greater chance of being infected). This initial map, then, constituted a baseline condition, and was used in the current investigation for comparison with other interpretive maps.

MODEL 1

Model 1 also used FRI label information. However, in this case, revised estimates of balsam fir plus white spruce dominance were applied to forest polygons in the study area (Figure 4). A weighted approach was followed to assign stand susceptibility in a stepwise manner: balsam fir plus white spruce stands with greater than 75% cover were classed as "very high", balsam fir plus white spruce stands over 50% dominance were considered "high", balsam fir plus black spruce dominated stands over 25% dominance were considered as "moderate", and all other conditions were classed as "low". This model, while still very simple, presents some advantages over the basic two class susceptibility map, because it provides some spatial patterns and area/volume details that might help the forester interpret general zones of higher and lower vulnerability.

MODEL 2

Model 2 was a preliminary model constructed for budworm vulnerability assessment in northwestern Ontario (Racey et al. 1989). This technique, based upon the NWO FEC system (Sims et al. 1989) used as primary building blocks, the 38 Vegetation Types and 22 Soil Types identified by the system. Map layers used in the construction of model 2 were NWO FEC Vegetation Type, Soil Type, soil depth, and soil drainage moisture overlays (Figure 5).

The model initially assigned NWO FEC Vegetation Types to four vulnerability classes: mixedwood and conifer Vegetation Types with balsam fir or white spruce as the dominant or co-dominant tree species, based on percentage ground cover by the canopy (V13-V16, V24, V25; "very high"), mostly mixedwood Vegetation Types with balsam fir or white spruce as a common overstory component (V5-V7, V10-12, V19, V33; "high"), mostly conifer stands with balsam fir and white spruce as occasional overstory components, but with these species common in the shrub layer (V3, V4, V8, V9, V17, V29, V31, V35, V36; "moderate"), and all other conditions were classed as

"low". In this model, emphasis is placed on stand composition and stand structure which are known to influence spruce budworm vulnerability (Bakuzis and Hansen 1965, Johnston 1977).

As a secondary feature, model 2 incorporated consideration of some selected soil features. Stands composed of trees with reduced vigour resulting from site-induced stress are more vulnerable to mortality from budworm attack. Very dry sites (NWO FEC Soil Types SS1, SS2, SS3, SS4) and very wet sites (NWO FEC Soil Types S12F, S12S, SS9) are expected to have increased vulnerability due to stress. Consequently, stands occupying soils with these moisture conditions were "bumped up" one class of vulnerability in model 2.

MODEL 3

Model 3 was somewhat more detailed and was based on Gagnon and Chabot's (1989) "vulnerability index" for spruce budworm infestation (Figure 6). This index incorporates several factors including stand composition and the percentage occurrence of balsam fir, stand age, stand density, as well as soil texture, drainage and depth. Using SPANS' modelling routine, eight map layers (FRI stand age, estimated FRI site index at age 50, a stand area index, NWO FEC Vegetation Type, NWO FEC Soil Type, soil drainage, soil texture, soil depth) were used.

Map layers were considered and weighted together to develop an index approximating Gagnon and Chabot's (1989) model. Generalized vulnerability classes were defined as follows: 1) large, older (over 70 years) balsam fir dominated stands (76% or greater dominance) of high density, and poor site class on coarse or fine textured, very rapidly or poorly drained soils ("extremely high"); 2) smaller and/or young to mature stands (mostly under 70 years) of balsam fir plus white spruce dominated stands (51% or greater dominance) on well drained, loamy to sandy, shallow (less than 100 cm) soils ("very high"); 3) smaller and/or young to mature stands (mostly under 50 years) of balsam fir plus white spruce dominated stands (26 to 75% dominance) on well drained, loamy to sandy, (shallow or) deep soils ("high"); 4) all other stands supporting balsam fir with either white spruce or black spruce as an occasional overstory component or a common understory component ("moderate"): and, 5) all other forest stand conditions ("low").

Large, or contiguous stands greater than about 70 years of age are considered to be at much higher risk than younger stands; susceptibility to attack furthermore increases substantially between 50 and 70 years of age (Blais 1958). MacLean (1980) showed that the mortality rate in older balsam fir stands undergoing infestation is between 60 and 100%, whereas in younger stands it was 30 to 60%. Small, isolated stands are felt to have considerably reduced risk of infestation. These conditions were dealt with in assigning stands between "extremely high" and "very high" vulnerability classes in model 3.

Budworm larval development is more closely synchronized with shoot elongation of balsam fir than of white spruce (Bakuzis and Hansen 1965). Moreover, white spruce produces 2 to 3 times more annual foliage than balsam fir (Gagnon and Hardy 1983). As a result, white spruce is not as vulnerable to budworm as balsam fir. Recent studies have indicated that vulnerability is higher on sites where drainage is either excessive or poor, where soils are shallow, or where soil texture is very coarse of very fine (Hix et al. 1987, Mott 1963, Gagnon and Chabot 1989). In model 3, these conditions were dealt with in assigning stands among "extremely high", "very high" and "high" vulnerability classes.

5.0 SUMMARY AND CONCLUSIONS

In general, similar trends were shown by all three models, and all compared favourably to the simple and generalized "susceptibility" map. Similar areas were allocated into approximately the same vulnerability levels by models 1 and 2, while model 3 reflected some reassignments. Although model 3 represented the most detailed and "elegant" of the three, it is difficult to say, from a cursory inspection, which of the models provided the most accurate predictive capabilities. All three models gave additional detail that would likely be useful for forest management planning.

A fair and critical assessment of the "workability" of these predictive models poses problems which unfortunately are common dilemmas for GIS modellers and users alike. One might assume that because these models were based on tangible data and scientific principles that they would reflect real situations. However testing or validating these in a scientifically acceptable manner is very difficult. In forestry, where predictive models often involve long-term growth or stand development scenarios that may span several decades, such problems are intensified. It would take many years to field test the validity of the models provided here. Even so, normal successional or stand development patterns in the boreal forest are often interrupted and modified by a wide range of other factors.

One important benefit of such models is the development of "working hypotheses". The current models may be of particular interest to entomologists and population biologists as bases for future research. They may provide operational foresters with some ideas and directions as to how to refine vulnerability estimates and incorporate such information into planning processes. Because the databases are computerized, other classes and other variables may be readily defined and examined using other models; in an operational setting, foresters might perhaps find it more satisfactory to review the mapped output of a few or several budworm vulnerability models to help them decide on an appropriate management strategy for a given forest area.

Forest managers need to be able to identify and weigh together those factors that influence the natural vulnerability of forest ecosystems to destructive pests. Many of those factors are understood, but not well enough to be quantified or priorized on an area by area basis. Nonetheless, the judicious use of GIS --that is, the careful combination of theoretical understanding with on-the-ground knowledge -- provides a powerful means of addressing the problem.

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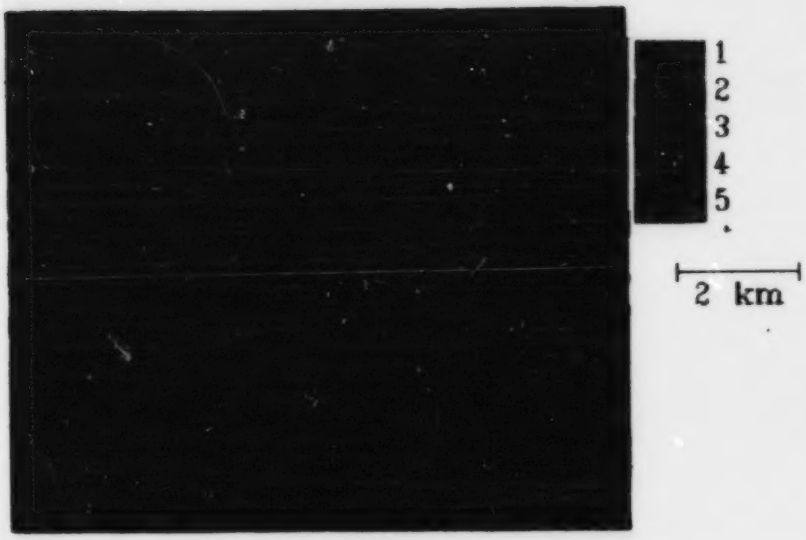

Figure 4. Model 1 - susceptibility based upon FRI stand typing and occurence of white spruce and/or balsam fir in the stand.

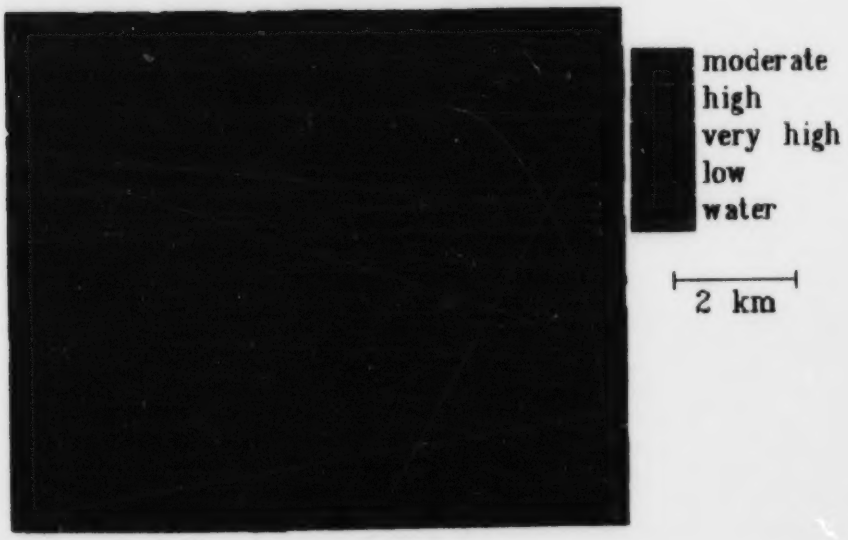

Figure 5. Model 2 - susceptibility based upon NWO-FEC stand descriptions and interpretations developed by Racey et al. 1989.

Figure 6. Model 3 - susceptibility based upon Gagnon and Chabot's (1989) "vulnerability index" for spruce budworm infestation using a combination of FRI and NWO-FEC stand typing.